Reprinted from: Watershed Research Perspectives. 1986. David L. Correll (ed.) Smithsonian Institution Press. Washington, D.C.

CONTROLLED AGRICULTURAL DRAINAGE: AN ALTERNATIVE TO RIPARIAN VEGETATION

CONTROLLED AGRICULTURAL DRAINAGE: AN ALTERNATIVE TO RIPARIAN VEGETATION

J. W. Gilliam, R. W. Skaggs and C.W. Doty[1]

Abstract-Drainage system design and management can be utilized to minimize offsite water quality effects of improved agricultural drainage. Improvement of subsurface drainage can cause a 10-fold increase in NO_3-N efflux. This increase can be partially offset by using controlled drainage which can reduce the NO_3-N efflux by as much as 50% in some situations. However, controlled drainage may slightly increase the phosphorus efflux, because of increased loss of water through surface runoff.

The design of controlled drainage systems must be site specific. This paper describes the effects of controls placed in collector tile lines, field collector ditches and large channelized streams on nutrient efflux.

INTRODUCTION

Riparian areas bordering agricultural fields in the North Carolina Coastal Plain are effective for improving the quality of drainage water from agricultural fields. When surface drainage water passes over these areas, much of the sediment and P are removed before the drainage water reaches a major stream (Cooper et al., 1985). When subsurface flow moves through a riparian zone, much of the nitrate is removed by denitrification (Jacobs and Gilliam, 1985); but it is not always practical or possible to pass agricultural drainage water over or through riparian areas. Design and management of the drainage system can influence the nutrient content of drainage water as well as time distribution of the outflows from essentially all land where improved drainage is necessary for agricultural production.

In this paper, drainage system design refers to whether a field is largely surface or subsurface drained as well as spacing and depth of improved subsurface drainage system. Controlled drainage refers to restricting the flow of subsurface drains by the use of some mechanical structure.

[1]Professors, North Carolina State University, Raleigh, NC and Agric. Engr. USDA-ARS, Florence, SC, respectively. Paper No. 10109 of the Journal Series of the North Carolina Agricultural Research Service.

CHARACTERISTICS OF IMPROVED AGRICULTURAL DRAINAGE SYSTEMS

Several drainage system designs can be utilized to satisfy the drainage requirements for agriculture. In the North Carolina Coastal Plain and along much of the Atlantic Coast, conventional agricultural drainage systems are designed primarily to remove surface water. Open ditches are dug about 100 m apart and the land surface is sloped toward the ditches to facilitate surface drainage to the ditches. In most soils, the ditches are too far apart to provide good subsurface drainage. When rainfall occurs, the water table often rises to the surface causing much of the drainage water to leave the field as surface runoff. These drainage conditions are not sufficient for economically viable yield on many soils (Skaggs and Tabrizi, 1983).

An alternative drainage system involves the use of more closely spaced drains to provide good subsurface drainage. Although open ditches can be used, buried tubes are normally installed at intervals that depend on the soil properties, climatological factors and crop to be grown. The utilization of this drainage system is becoming much more common in poorly drained Coastal Plain soils because of increased yields as compared to systems with primarily surface drainage. Tube drainage systems at proper spacings also offer more management opportunities for efficient water use and water quality improvement.

There are significant differences in the outflow rates from a field that is surface-drained than from one with good subsurface drainage. The peak outflow from a surface drained field is greater than from a similar field with good subsurface drainage. Subsurface drains remove excess water from the soil profile over a long period of time compared to surface runoff events. This lowers the water table which provides more storage for infiltration from subsequent rainfall thereby reducing surface runoff.

An example of the effect of good subsurface drainage on outflow rates is shown in Fig. 1 (Gilliam and Skaggs, 1985). The outflow rates plotted were measured on adjacent 36 ha watersheds near Belhaven, North Carolina for a 32 mm rainfall event in Feb. 1985. The watersheds are essentially flat (slopes less than 2%) and each watershed is composed of the same shallow organic and mineral soils. The only known difference is that one watershed has a conventional drainage system with open ditches 100 m apart while the other watershed has two additional tile lines, equally spaced between each pair of ditches, providing good subsurface drainage. The peak flow rate from the watershed with good subsurface drainage was about half of that measured for the watershed with poor subsurface drainage. The flow event was extended over a longer period of time for the watershed with good subsurface drainage. The total outflow was about the same for both watersheds, but good subsurface drainage reduced the peak flow rate.

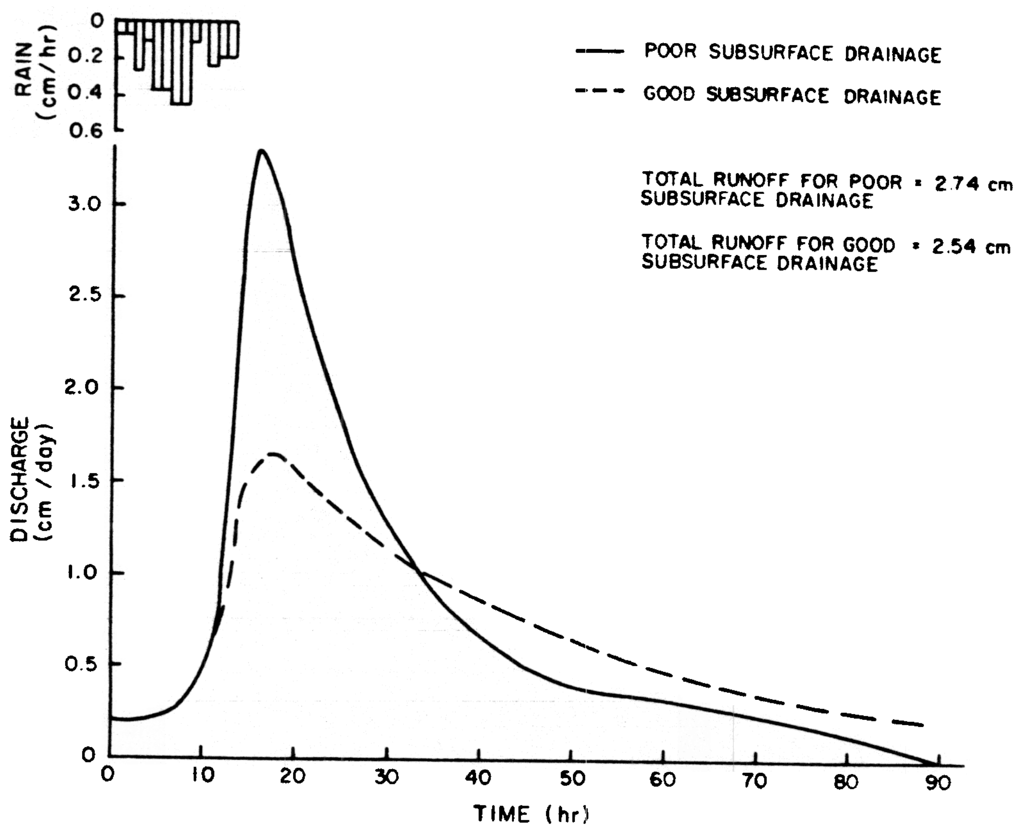


Figure 1. The effect of improved subsurface drainage on peak discharge rates.

Simulation modeling studies (Skaggs and Tabrizi, 1981) on a similar soil showed that annual surface runoff could be reduced by a factor of three (from 57 cm to 19 cm) by reducing the drain spacing from 100 m to 15 m. Annual subsurface drainage was increased by a similar amount. The results of these studies show clearly that the drainage system design significantly affects the amount and rate of surface runoff--on both an annual basis as well as for single storm events. Changes in rate and distribution of runoff implies an effect on erosion and pollutant movement carried in the surface and subsurface drainage waters from these poorly drained soils.

The proportion of the drainage water which leaves agricultural fields via surface or subsurface drainage has a large influence upon the potential pollutants carried by the water (Baker and Johnson, 1976; Bengtson et al., 1982; Gilliam and Skaggs, 1985). Surface runoff carries more sediments, pesticides and phosphorus than subsurface flows. But the higher proportion of subsurface flow is accompanied by a greater loss of nitrate-nitrogen and generally a greater loss of total N. The effects on N and P losses are illustrated by data in Table 1 from the Coastal Plain of North Carolina.

Table 1. Effect of type of drainage on N and P efflux in drainage water from three similarly cropped soils in the North Carolina Coastal Plain.

	Drainage Type		
Nutrient	Poor Subsurface	Intermediate	Good Subsurface
	-------------------	kg ha^{-1} yr^{-1}	-------------------
NO_3-N	4.1	17.6	36.3
Total-N	15.2	22.4	47.2
Total-P	0.60	0.33	0.24

The three fields from which the data in Table 1 were collected were in a corn-soybean rotation and cultural practices were very similar. The field with poor subsurface drainage contained ditches spaced approximately 100 m apart, but the internal conductivity was so poor that most drainage water was removed via surface runoff. The intermediate field had a similar drainage system but this field had a sand layer present at a depth of approximately 1 m. This sand layer improved the drainage to the open ditches, but this field was still not as well drained as one with two equally spaced drain tubes installed parallel to the open ditches. In the field with good subsurface drainage nearly all drainage water reached the open ditches via subsurface flow. The large effect that the type of drainage has upon nutrient outflows (Table 1) has significant implications for the design and management of drainage systems.

Approximately half the drainage water from agricultural land in North Carolina occurs during the period December through March (Fig. 2). In many cropping systems, drainage during this period is not agriculturally critical, so drainage water can be managed to minimize nutrient outflows without influencing agricultural production. Our initial experiments on controlled drainage were designed to control water only during the winter, but we now know that controlled drainage throughout the year offers potential for increased agricultural production as well as providing environmental benefits.

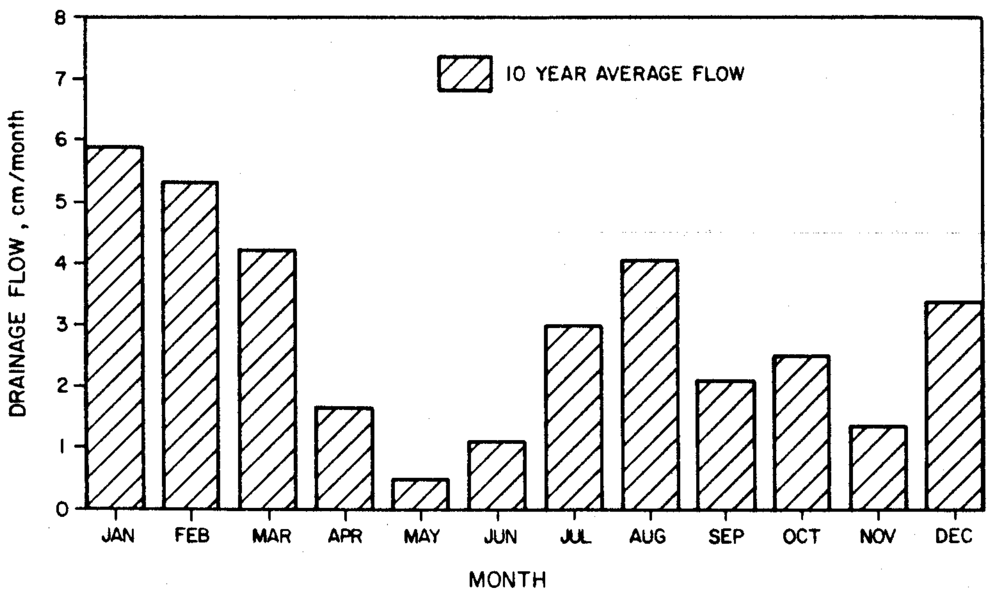


Figure 2. Average monthly discharge as predicted by DRAINMOD (Skaggs, 1978) for a cropped Goldsboro soil in North Carolina.

CONTROLLED DRAINAGE FROM AGRICULTURAL FIELDS

<u>Moderately well drained soils</u> - It must be emphasized that to be most effective the drainage system design must be site specific and effective controlled drainage design systems are also site specific. For moderately well drained soils of the Middle Coastal Plain, control structures in collector ditches from relatively large areas generally are not feasible because slopes are too great. Installation of control structures in main

tile outlets is possible and the effect that control structures can have upon NO_3-N outflows from the tile outlets is shown in Fig. 3. The reduction due to drainage control in the total amount of NO_3-N loss through the tile lines is a result of decrease in the amount of water passing through the tile lines and not due to any reduction in NO_3-N concentration. We found no evidence that controlled drainage increased the amount of N lost to denitrification in these fields so it is assumed that approximately equal quantities of NO_3-N left the controlled and uncontrolled fields in drainage water. However, in the uncontrolled fields,-approximately 35 kg ha^{-1} yr^{-1} of NO_3-N was added directly to surface waters through tile drainage. The drainage water from the controlled fields would have to enter surface water in different areas. Other experiments have shown that much of the NO_3-N is removed from drainage water when the subsurface water enters surface water through ditch banks or riparian areas (Jacobs and Gilliam, 1985; Cooper et al., 1985). Thus the controlled drainage in these moderately well drained soils probably prevented a large percentage of the NO_3-N from entering surface water as compared to uncontrolled drainage. This control system would seem to have potential water quality benefits anywhere that improved subsurface drainage systems are used.

Poorly drained soils - In poorly drained and very poorly drained flat soils of the Lower Coastal Plain, flashboard risers in collection ditches have been used to control water tables in fields up to 40 ha in size. These poorly drained soils have enough organic matter in the top 2 m of the profile to cause reducing conditions below the water table (Fig. 4). Nitrate which moves into the saturated zone is quickly reduced through denitrification (Gambrell et al., 1975). This is shown in Fig. 4 where the nitrate-nitrogen concentrations are < 0.05 mg L^{-1} below 1 m. Water passing through this zone on the way to an outlet has essentially all of the NO_3-N removed from it.

Because of the higher water table maintained with controlled drainage, surface runoff will be increased. Since surface runoff contains a higher concentration of P than subsurface flow, an increase in P losses would be

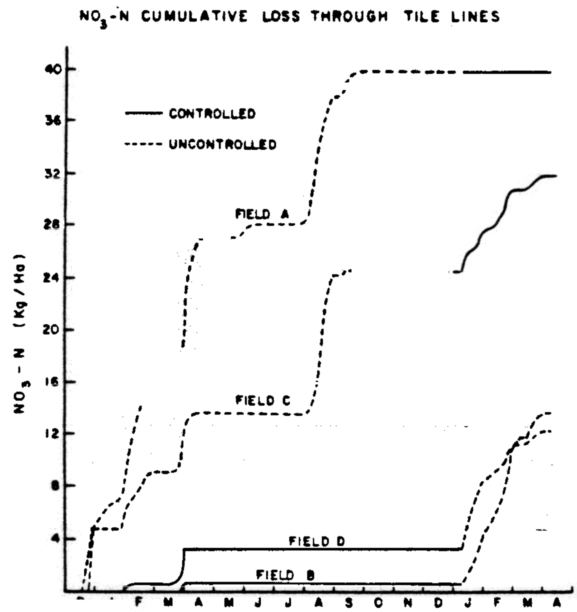


Fig. 3. The effect of controlled drainage on nitrate loss through tile drainage lines (Gilliam et al. 1979).

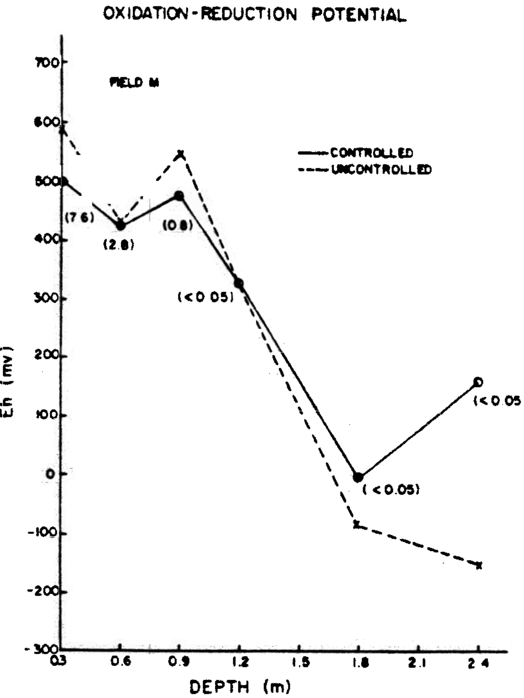


Fig. 4. Oxidation-reduction potential with depth in a poorly drained high water table soil. Numbers in parenthesis are average NO_3-N concentrations (mg L^{-1}) in soil water at each depth (Gilliam et al. 1984).

expected under controlled drainage. The data in Table 1 are a good indication of the potential effects of controlled drainage on N and P effluxes from a naturally poorly drained lower Coastal Plain soil with a good subsurface drainage system installed on it. The good subsurface drainage represents the conditions which exist under no control and the poor subsurface drainage represents maximum control throughout the year. It would be expected that actual control conditions would be between these two extremes with regard to N and P losses to surface water.

Deal et al. (1985) used nutrient losses measured in several experiments under different types of drainage (Gambrell et al., 1974; Gilliam et al., 1979; Skaggs et al., 1980) in conjuction with the water management model DRAINMOD (Skaggs, 1978) to predict surface runoff, subsurface drainage, and nutrient losses for six soils for hypothetical field drainage conditions. The soils modeled were poorly drained to very poorly drained and all had a high water table (< 1 m) during much of the year unless improved drainage systems were installed. For each nutrient loss simulation, a 20 year long period of climatological data was used with DRAINMOD. During the period used (1950-1969), the average annual precipitation was 120 cm with a range of 86 to 159 cm. Water and nutrient losses for each soil were simulated for four combinations of surface-subsurface drainage with and without drainage control. Controlled drainage consisted of raising the control structures to within 30 cm of the surface from 1 December to 11 March each year. The control structures were then lowered to 1 m to allow tile drainage to proceed. Lowering the control structures in March was necessary for land preparation and planting. The controls remained at 1 m until 16 June to allow establishment of the crop and then were raised to within 45 cm of the surface. The structures remained at 45 cm until 1 September when they were lowered again to 1 m to facilitate harvesting and remained there until 1 December when the schedule was repeated. Data are reported as annual averages.

It can be observed from the data given in Table 2 for two soils that controlled drainage was predicted to significantly reduce NO_3-N efflux, particularly under good subsurface drainage conditions. Drainage control was predicted to have some effect on soils with poor subsurface drainage but this effect was relatively small. We wish to emphasize that NO_3-N reductions under controlled drainage in fields with good subsurface drainage cannot be extrapolated to soils with poor subsurface drainage.

In general, mechanical control of the water level also decreased the total efflux of total Kjeldahl N (TKN). Even though surface loss increased with controlled drainage, the subsurface efflux decreased by a greater amount so that a net decrease in total TKN occurred with controlled drainage.

The negative side of controlled drainage from an environmental viewpoint is that total P efflux in drainage water was increased (Table 2). The increase in P efflux was much less than the decrease in N efflux but is a factor which must be considered in management of agricultural drainage water.

Because the simulations considered no deep seepage of drainage water, the effect of controlled drainage in reducing nutrient effluxes are minimized. It is known that controlled drainage usually increases deep or lateral seepage. The water which leaves the field via this mechanism is expected to contain a very low concentration of both N and P because of denitrification and P fixation by the subsoils. We have measured as much as a 50% reduction in flow in collection ditches from controlled drainage fields as compared to uncontrolled fields of similar soils (Gilliam et al., 1979). Controls in these fields reduced the nutrient efflux more than those predicted by the modeling techniques employed to generate the data in Table 2. However, we would not expect controlled drainage to reduce outflows in drainage ditches by 50% so we predicted no deep seepage in generating data for Table 2. We currently are conducting field experiments to obtain data to allow us to better predict the effects of deep seepage under controlled drainage upon water and nutrient effluxes.

Table 2. Prediction of annual nutrient efflux under various drainage designs under condition of no deep seepage. (From Deal et al., 1985)

Soil	Drainage Practice*	NO_3-N		TKN		P	
		Uncon**	Con***	Uncon	Con	Uncon	Con
		kg ha^{-1} yr^{-1}					
Portsmouth	A	43.9	33.9	6.4	5.7	0.06	0.07
	B	43.5	29.7	6.3	5.4	0.10	0.18
	C	13.0	8.3	5.4	4.7	0.23	0.33
	D	12.0	8.0	5.0	4.1	0.14	0.24
Wasda	A	31.5	24.5	5.7	5.4	0.11	0.12
	B	31.2	21.4	6.1	5.8	0.20	0.31
	C	2.5	1.9	6.9	7.2	0.57	0.67
	D	2.1	1.6	5.4	5.6	0.37	0.51

*A = poor surface drainage-good subsurface drainage; B = good surface drainage-good subsurface drainage; C = good surface drainage-poor subsurface drainage; D = poor surface drainage-poor subsurface drainage.

**Uncontrolled drainage
***Controlled drainage

CONTROLLED DRAINAGE FROM WATERSHED SCALE AREAS

Under Public Law 566-Drainage Projects, many streams draining agricultural watersheds have been channelized. When Public Law 566 was initiated, only the agricultural benefits of channelization were generally recognized. Since that time offsite effects resulting from increased nutrient effluxes have been discussed (O'Rear, 1975) as well as onsite effects on wildlife (Tiner, 1984). When most drainage projects were designed, no management of the drainage water was envisioned. Furthermore, most critics of the drainage projects assume that no management is possible.

The Conetoe Drainage District in North Carolina was instrumental in improving the drainage of 26,000 ha of land in 1967. It is a good example of a channelization project. Several thousand ha of cropland that once were flooded several times a year are now protected against flooding. Although flooding is no longer a major problem in the District, overdrainage in some areas and lack of sufficient water for irrigation are problems. We initiated a cooperative research project among USDA-ARS, NC-ARS and USDA-SCS in 1979 to evaluate the effects of controlling the drainage in one channelized stream in this watershed on water utilization for agricultural production of row crops. Another important objective was to determine the effect of controlled drainage on quality of the water leaving the watershed.

The study area is a 3.2 km section of a channelized stream (Mitchell Creek) which drains about 3200 ha above the study area and 700 ha in the study area. Six lines of wells were installed perpendicular to the creek on each side to measure water table elevations as well as quality of ground water moving toward the creek. A fabridam (Fig. 5) was installed in April to control the water level in the creek. The fabridam is capable of controlling the water level at any desired level between 2.45 and 11.75 m above MSL.

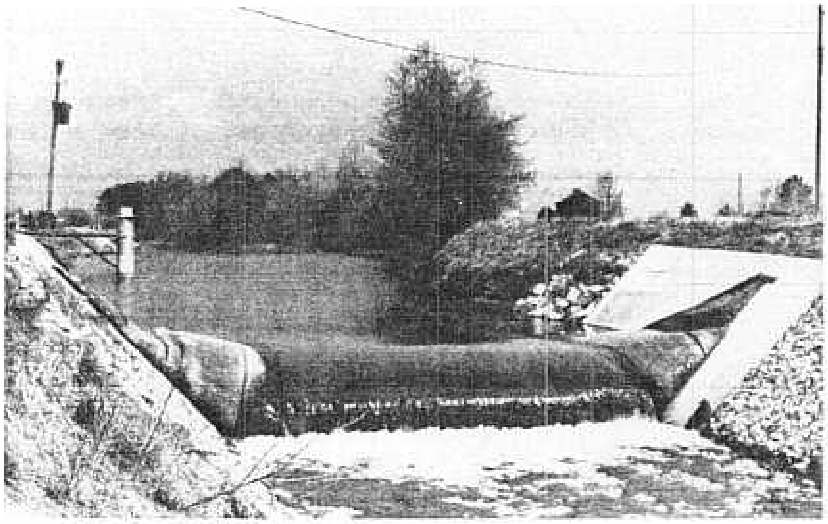


Fig. 5. Fabridam structure used for water control in a channelized stream.

This project has attracted much attention primarily because of the positive effect of the control upon water table and crop yields (Doty et al., 1984). Controlled drainage has also had an apparent positive effect on some parameters of quality of the drainage water leaving the study area. The effect of the control upon concentrations of N and P are given in Table 3. The largest effect of control was on the NO_3-N concentration. During the previous three years before control, NO_3-N concentration in the stream increased as it flowed through the stream reach affected by the control structure (control section). It is believed that this increase is a result of the more intensive agricultural development and cultural practices of the area draining into the creek in the control section as compared to the upstream area. Nearly all of the area draining into the control section is under cultivation, whereas a significant percentage of the upstream area contains unmanaged forest.

Table 3. Effect of controlled drainage in a channelized stream on nutrient concentrations. Concentrations are averages of weekly samples.

	Year				
	Before Control			After Control	
	79-80	80-81	81-82	82-83	83-84
	NO_3-N in Control Section (mg L^{-1})				
Entry	2.6	2.2	1.9	2.9	4.2
Exit	3.0	2.6	2.7	1.5	3.2
% Change	+15	+18	+42	-48	-23
	Total N in Control Section (mg L^{-1})				
Entry	3.7	2.6	2.5	3.2	4.7
Exit	3.7	3.0	3.4	2.0	3.6
% Change	0	+23	+36	-37	-23
	Total P in Control Section (mg L^{-1})				
Entry	.03	.02	.01	.07	.02
Exit	.04	.06	.13	.04	.04
% Change	+33	+200	+1200	-43	+100

After the fabridam was installed, there was a decrease in NO_3-N concentration as the water moved through the controlled area of the stream. It is unfortunate that we do not have an accurate measure of flow as the stream entered and left the control area so that total nutrient fluxes could be computed as well as flow weighed concentrations. We expended much effort to measure flows but were unsuccessful due to variable resistance to flow caused by the extensive weed growth in the creek.

Three factors are believed to contribute to the decrease in NO_3-N after the fabridam was installed. One factor is an increase in denitrification in the more poorly drained soils toward the outer edge of the drainage area influenced by the control. The effect of control on the water table in the fields adjacent to the creek is shown in Fig. 6. Also shown are the average NO_3-N concentrations in the ground water in a transect below the fields. The NO_3-N concentrations at the outer edge of the drainage area were always lower, presumably because of more denitrification in these more poorly drained sections. Even though the water table control influenced the water table less at the outer edge, it is in this region that slight changes in water table elevation can result in significantly more denitrification. The average NO_3-N in the wells immediately adjacent to the stream was 9.2 mg L^{-1} (95 samples) before control and 5.0 mg L^{-1} (177 samples) after control.

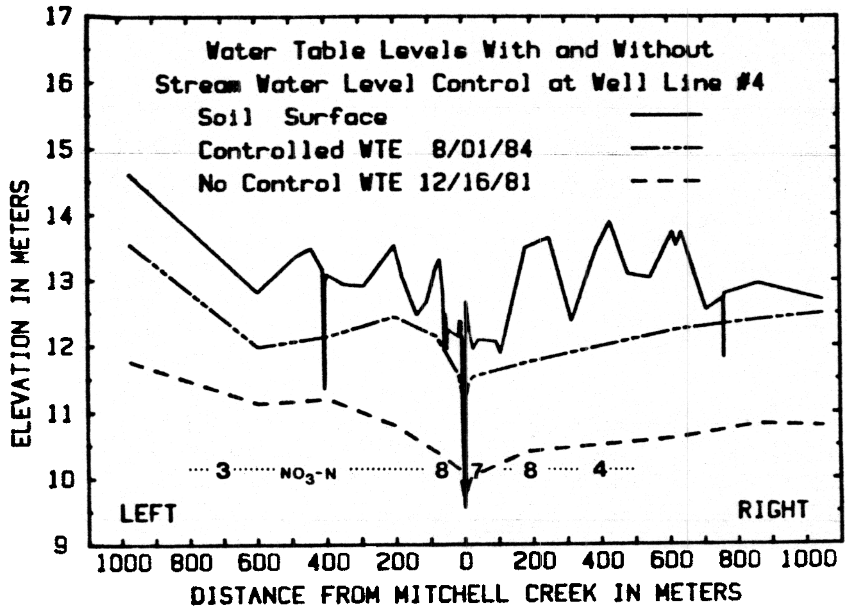
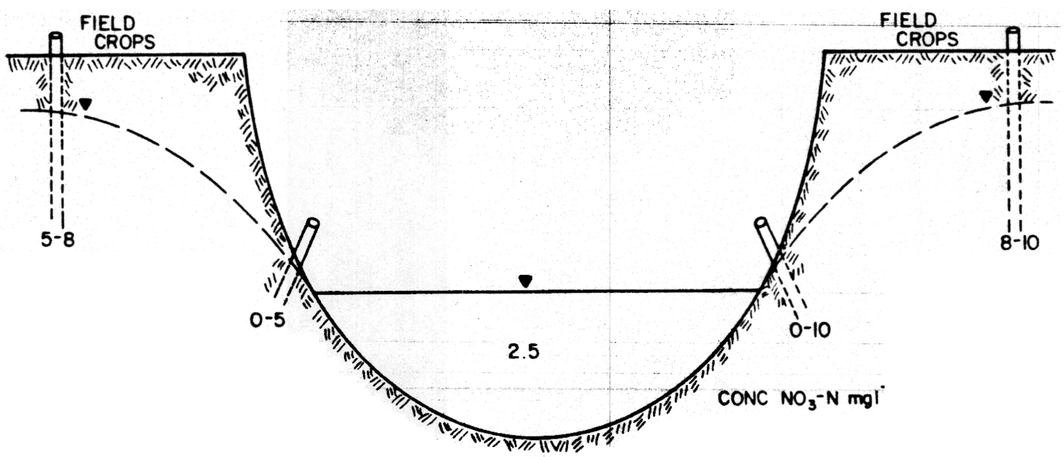


Fig. 6. Water table levels with and without control in a channelized stream. The numbers across the lower portion of the figure are average NO_3-N concentrations (mg L^{-1}) in the shallow ground water.

There is a further reduction in the NO_3-N concentration because of denitrification as the water flows from the field into the ditch. This is illustrated in Fig. 7 for a lateral ditch which flowed into the main channelized stream. The ground water in the fields on either side of the ditch which drained into the ditch contained 5-8 mg L^{-1} and 8-10 mg L^{-1} of NO_3-N. The ditch water concentration was approximately 2.5 mg L^{-1}. Numerous samples taken in the ground water within 1 m of the ditch bank contained from zero to the same NO_3-N concentrations as that in the field. Oxidation-reduction potential measurements taken in this area showed that much of the area was highly reduced so conditions for denitrification were favorable. These conditions exist whether water table control is used or not but it is believed that the higher the water table, the greater the probability that drainage water will pass through an area adjacent to the ditch which is conducive to denitrification.



Fiq 7. Nitrate-nitrogen concentrations in a lateral ditch which drains into the channelized stream, in ground water in fields on either side of the ditch and in water within 1 m of the ditch bank.

The third factor believed responsible for the decrease in NO_3-N in the control section is denitrification in the ditch itself. As mentioned above, the ditch contained a large growth of weeds. Even during periods of moderate flow, stagnant areas could be seen in the channelized stream. The effect that the reducing conditions measured in these areas, as well as the generally reducing conditions below the stream bed, have on NO_3-N concentration in a profile of the stream water is shown in Fig. 8. The concentration of NO_3-N in the bulk solution was 2.6-2.7 mg L^{-1}. It is apparent that NO_3-N concentration is not uniform across the stream. The generally lower concentration in the bottom sample (as close to the bottom as possible to sample) is a result of the highly reducing conditions and near zero NO_3-N concentration below the stream bed. The lower concentrations on the right hand side of the stream were measured in a relatively stagnant pool of water. Again, these processes occur whether the stream level is controlled or not; but the residence time of water in the control section is greater during periods of control. For example, the cross-sectional areas taken on Mitchell Creek show that when the depth of water in the creek is increased from 0.5 to 2.5 m, the wetted perimeter of the water interface in contact with the soil surface increases three-fold. This increases the probability for denitrification to occur.

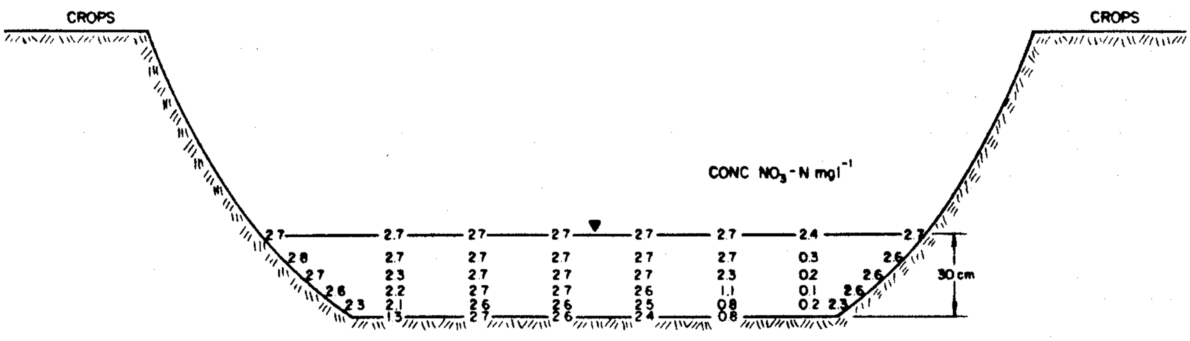


Fig. 8. Nitrate-nitrogen concentrations in a cross section of the channelized stream. Numbers are averages of three samples taken over a 24-hour period.

The effect of control on total N concentration was nearly the same as for NO_3-N because NO_3-N makes up a large percentage of the total N. Most of the difference between total N and NO_3-N is organic N because NH_4-N concentration is usually < 0.1 mg L^{-1}.

There was an inconsistent effect of watershed drainage control on P concentration in the control section. Processes responsible for the nitrogen decreases are not effective for removal of P. Actually the P levels measured in this stream are about as low as can be expected for drainage water from agricultural watersheds in the Atlantic Coastal Plain. The low P levels are probably a result of the high hydraulic conductivity in deep sands adjacent to the ditch. Most water entering the channel enters by subsurface flow which contains little P.

SUMMARY

The utilization of controlled subsurface drainage offers potential for reducing offsite nutrient inputs as a result of improved agricultural drainage. Management can also be used to distribute the drainage flow over a longer period of time to reduce peak outflow rates. It can reduce the nitrogen content, particularly NO_3-N, of the drainage water. Drainage control systems which increase surface runoff do tend to slightly increase the P content of the drainage water.

Water management techniques to improve the quality of agricultural drainage water are very attractive to those concerned with agricultural production because it offers the potential for increased crop yields. Several controlled drainage systems have recently been installed in Eastern North Carolina with the anticipation of increased crop yields. These systems have also been recognized by regulatory agencies and SCS as a Best Management Practice in North Carolina and cost sharing is available in nutrient sensitive watersheds.

LITERATURE CITED

Baker, J.L. and H.P. Johnson. 1976. Impact of subsurface drainage on water quality. pp. 91-98. In Proceedings of 3rd National Drainage Symposium ASAE Publication No. 77-1.

Bengtson, R.S., C.E. Carter, H.F. Morris and J.G. Kowalczk. 1982. Reducing water pollution with subsurface drainage. Paper No. 82-2554. ASAE Annual Meeting Dec. 14-17. Chicago, Ill.

Cooper, J.R., J.W. Gilliam and T.C. Jacobs. 1985. Riparian vegetation for the control of nonpoint pollutants. This book).

Deal, S.C., J.W. Gilliam, R.W. Skaggs and K.D. Konya. 1985. Prediction of nitrogen and phosphorus losses from selected North Carolina Coastal Plain soils as related to drainage system design. Submitted to J. Environ. Qual.

Doty, C.W., J.E. Parsons, A. Nassehzadeh-Tabrizi, R.W. Skaggs and A.W. Badr. 1984. Stream water levels affect field water tables and corn yields. Trans. ASAE 27:1300-1306.

Gambrell, R.P., J.W. Gilliam and S.B. Weed. 1975. Denitrification in subsoils of the North Carolina Coastal Plain as affected by soil drainage. J. Environ. Qual. 4:311-315.

Gambrell, R.P., J.W. Gilliam and S.B. Weed. 1974. The fate of fertilizer nutrients as related to water quality in the North Carolina Coastal Plain. Water Resources Research Institute of the University of N.C. Report No. 93.

Gilliam, J.W. and R.W. Skaggs. 1985. Use of drainage control to minimize potential detrimental effects of improved drainage systems. Proceedings of A.S.C.E. National Specialty Conference - Irrigation and Drainage.

Gilliam, J.W., R.W. Skaggs and S.B. Weed. 1979. Drainage control to diminish nitrate loss from agricultural fields. J. Environ. Qual. 8:137-142.

Jacobs, T.C. and J.W. Gilliam. 1985. Nitrate losses between cropped fields and surface drainage waters in the North Carolina Coastal Plain. J. Environ. Qual. (In Press).

O'Rear, C.W. 1975. The effects of stream channelization on the distribution of nutrients and metals. Water Resources Research Institute of the University of N.C. Report No. 108.

Skaggs, R.W. 1978. A water management model for shallow water table soils. Water Resources Research Institute of the University of N.C. Report No. 134.

Skaggs, R.W., J.W. Gilliam, T.J. Sheets and J.S. Barnes. 1980. Effect of agricultural land development on drainage waters in the North Carolina Tidewater Region. Water Resources Research Institute of the University of N.C. Report No. 159.

Skaggs, R.W. and A. Nassehzadeh-Tabrizi. 1981. Effect of drainage system design on surface and subsurface runoff from artifically drained lands. In Proceedings of International Symposium on Rainfall-Runoff Modeling. May 18-21. Miss. State Univ., Miss. State, MS.

Skaggs, R.W. and A. Nassehzadeh-Tabrizi. 1983. Optimum Drainage for Corn Production. Tech. Bull. 274. North Carolina State University, Raleigh, NC.

Tiner, R.W. 1984. Wetlands of the United States: Current Status and Recent Trends. USDI Fish and Wildlife Service. U.S. Government Printing Office.

DISCUSSION: Gilliam Paper

Comment (Correll): I wonder whether or not you have enough organic matter in those soils to carry out more denitrifictaion or is that becoming a limiting factor when you flood the soils? Are those agricultural soils too poor in organic matter and especially the subsoils to drive denitrification further?

Answer: That is very definitely true, and is the reason I have said, I didn't think we increased the denitrification close to the main channel. Those subsoils do not have enough organic carbon to become reduced, and there is no indication we would ever get denitrification in that system where we have the Fabridams. Now that isn't true in poorly drained soil where we are controlling it on the field basis.

Question (Vorosmarty): I was wondering what proportion of denitrification was in the form in N_2O losses?

Answer: In most of these poorly drained fields we measured from 10 to 20 kg ha/yr coming off as N_2O.

Question (Vorosmarty): So about half of the loss would be N_2O?

Answer: Maybe a third. We have measured some fields where we get much higher. In some of the organic soils we have measured 50-60 kg ha/yr where we have low pH's, pH 4.5 - 4.8. But most agricultural fields where I talked about using control drainage we measured from 10 to 20 kg ha/yr coming off as N_2O.

Comment (Pionke): I noticed you were recommending this to farmers and there were large numbers of farmers involved. Under the conditions of a raised water table you had considerably higher phosphorus concentrations. This raises a lot of questions. The discharge of that watershed may contain increased trace metals or pesticides. What I am saying is that there may be some negative aspects to the reduction process.